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Presented is the establishment of a semiconductor optical properties characterization facility constructed at Arizona State University under the sponsorship of an AFOSR-URIP. The fully computerzied system is connected to our MBE and electrical properties characterization laboratory network and will be used for two purposes: (1) to study the properties of photonic materials and devices and (2) to study the growth kinetics in solid source and gas source molecular beam epitaxy. As a result of these efforts, a coherent research program has been established that stresses the following points: (1) collaborative research among engineering, physical science and materials science faculty specifically in the field of compound semiconductor (GaAs, AlGaAs, InGaAs and InP based) materials with emphasis on heterojunction and quantum well structures; (2) diagnostics of novel optoelectronic devices and materials; (3) interaction with our strong theoretical efforts to identify new directions in MBE growth and optoelectronic and nanostructure device physics. Several productive DoD programs have been obtained with utilize the equipment for student training and technical publications. The instrumentation has provided a capability for scientific research that is unique in any university.

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In Situ GSMBE Growth Monitoring for Optoelectronic Devices

FINAL REPORT

to

Air Force Office of Scientific Research
University Research Instrumentation Program (URIP)

AFOSR contract #: AFOSR 89-0180
ASU contract #: DWE 1746

by

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Abstract

Presented is the establishment of a semiconductor optical properties characterization facility constructed at Arizona State University under the sponsorship of an AFOSR-URIP. The fully computerized system is connected to our MBE and electrical properties characterization laboratory network and will be used for two purposes: (1) to study the properties of photonic materials and devices and (2) to study growth kinetics in solid source and gas source molecular beam epitaxy.

As a result of these efforts, a coherent research program has been established that stresses the following points: (1) collaborative research among engineering, physical science and materials science faculty specifically in the field of compound semiconductor (GaAs, AlGaAs, InGaAs and InP based) materials with emphasis on heterojunction and quantum well structures; (2) diagnostics of novel optoelectronic devices and materials; (3) interaction with our strong theoretical efforts to identify new directions in MBE growth and optoelectronic and nanostructure device physics. Several productive DoD programs have been obtained which utilize the equipment for student training and technical publications.

The instrumentation has provided a capability for scientific research that is unique in any U.S. university. Thus the training of students on modern instrumentation to effectively pursue present and future DoD research directions is progressing successfully.

Introduction

Semiconductor epitaxial growth technology has been progressing for several years and great strides have been made in material purity and heterojunction abruptness. The main contenders for a viable production technology are Molecular Beam Epitaxy (MBE) and Metalorganic Chemical Vapor Deposition (MOCVD) each having advantages for certain applications. It is generally thought that MBE produces superior electronic devices (eg. modulation doped field effect transistors) while MOCVD is better suited to photonic devices such as light emitters. An emerging technology is a hybrid of the two which uses gaseous sources in an ultrahigh vacuum chamber. Hydrides are used as group V sources and organometallics are used for the group III's. Solid sources are also used depending on the desired structure to be grown. Hence a variety of names have been coined to describe the various combinations of III and V sources. In this report. GSMBE (gas source MBE) will be used for convenience to describe MBE with gaseous sources (includes CBE and MOMBE). We have made operational, a set of laboratory facilities to grow GSMBE material, characterize it and fabricate devices. In addition, we have constructed the capability to couple three in-situ characterization techniques in attempts to understand GSMBE growth kinetics.

This Air Force University Instrumentation Program was the second granted to ASU for the establishment of MBE and supporting characterization facilities. As a result of this support, a unique capability has been established at ASU to grow III-V heterostructures and characterize them. The tight feedback between materials growth and characterization have enabled us, in a short time, to produce material of quality equal or better than that of other facilities in the world as well as to produce novel structures.

We would like to warmly thank AFOSR for providing ASU with the support necessary to start a new program and bring it to fruition.

Equipment and facilities developed under AF-URIP

Gas source MBE pumping/scrubbing system

In order to obtain monolayer abruptness in GSMBE, the group III and V sources must be switched abruptly; on the order of one second. To achieve this, a sophisticated system to simultaneously valve-off the gas flow and evacuate the dead space in the gas lines is necessary. Additionally, because of safety considerations, the lines must be purged safely and completely. We purchased such a system from VG Semicon. After extensive delays, we received it and made it operational.

An additional group III gas source was purchased which increased the number of available group III lines to three. These are triethylgallium (TEG), triethylalumirum (TEA) and trimethylindium (TMI). A solid source indium cell was purchased and put into the solid source MBE system to give us the capability of growing strained heterostructures.

Tunable lasers

A large frame argon ion laser (15 watts) was purchased to pump a tunable ring dye laser. The dye laser has extremely narrow linewidths ($<10^{-4}$ cm^{-1}) and is automatically tunable in the ultraviolet. This is being used to perform non-invasive measurements of the chemical reaction species at the growth surface by laser induced fluorescence (LIF) in real time.

We also managed to purchase a tunable, solid state laser which is also pumped by the argon ion laser. This titanium sapphire ($TiAl_2O_3$) system is used to perform photocurrent and excitation spectroscopies of finished materials and devices.

In-situ Ellipsometer for MBE

The MBE was custom designed with optical ports for ellipsometry and reflectivity measurements. Due to budgetary constraints, we originally budgeted a single wavelength ellipsometer and planned on designing and fabrication the MBE adapters ourselves. Fortunately we were able to enter into a collaboration with J. Woolam Inc. which enabled us to design and construct a system specifically suited to our needs and at the same time provide the company with designs, specifications of a real environment and access to our MBE data. This interaction has resulted in three major iterations of the system design to the point where we have an in-situ spectroscopic ellipsometer.

In summary, we have constructed, with AFOSR support, a comprehensive set of in-situ diagnostic techniques to study the growth of epitaxial material grown by gas source MBE. We thus have the capability to study the structural, chemical and optical properties of the material during growth. Figure 1 shows the present MBE system and its diagnostics. Figure 2 is a layout of the MBE laboratory and its supporting laboratories.

IN-SITU GAS SOURCE MBE GROWTH MONITORING SYSTEM

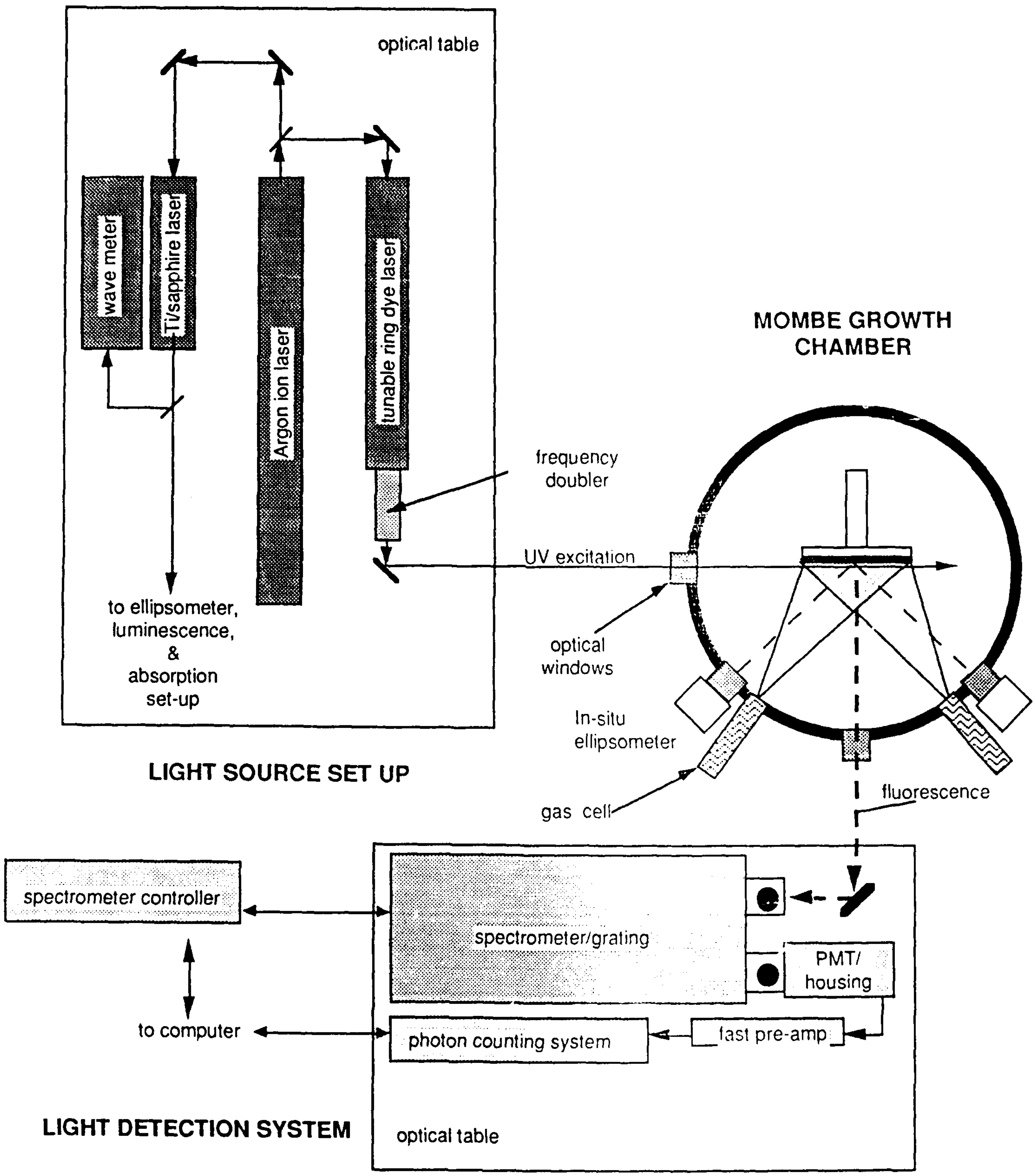

Figure 1. Schematic of in-situ monitoring system.

MBE lab and Characterization Facilities

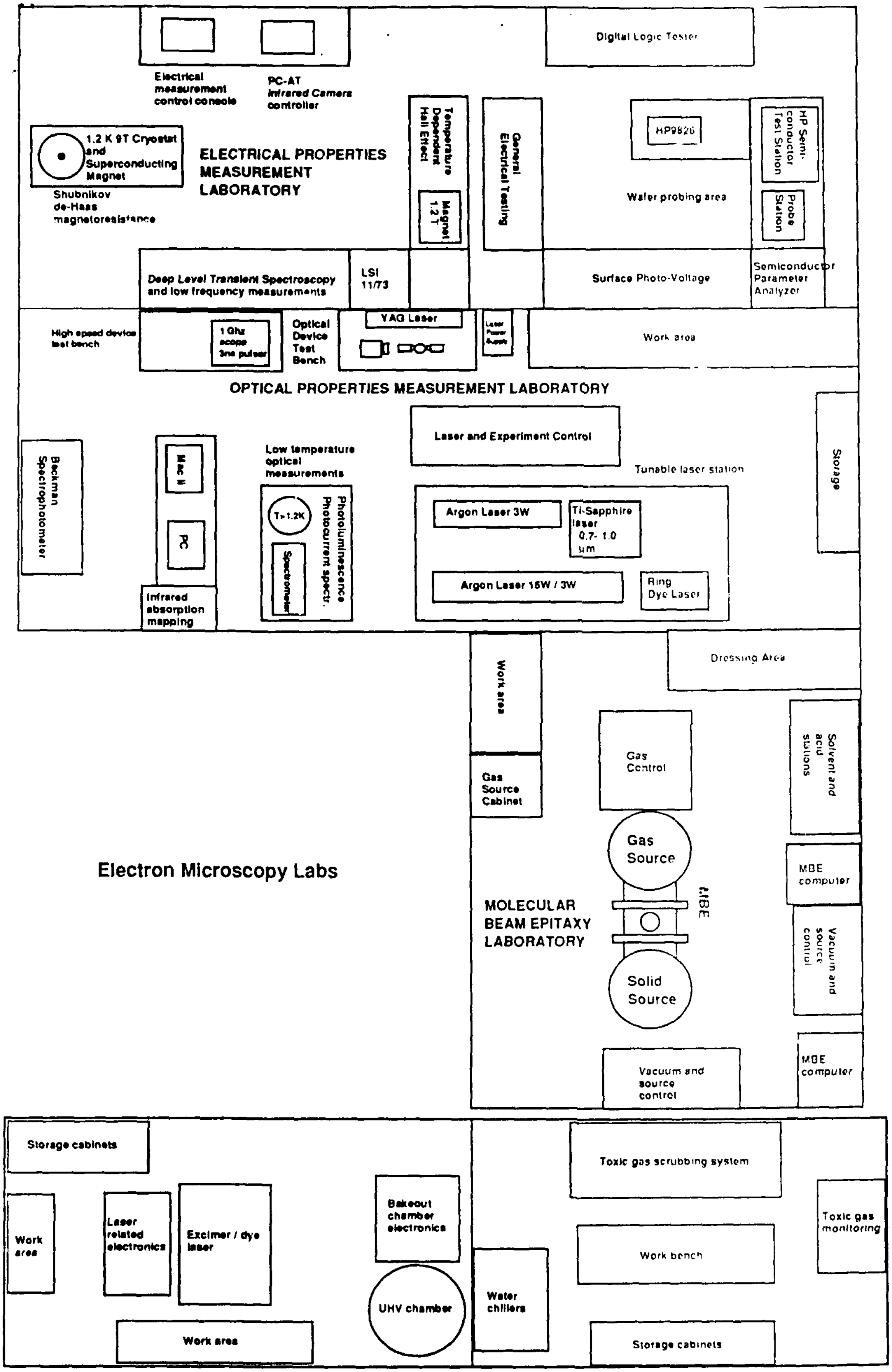

Figure 2. Layout of the MBE laboratory and its supporting laboratories.

Research programs established as a result of this URIP

The laboratories that we have constructed have enabled us to augment our present research programs and obtain new ones. A list of programs that directly use the facilities described here is shown below.

Sponsor	Program title
ARO	Isolation Mechanisms in III-V Devices
NSF	Presidential Young Investigator (PYI)
MOTOROLA/NSF	Modulation Doped Structure Research
MOTOROLA	CSSER Industrial Partners Program
DoD-URIP	In-situ characterization for Gas source MBE
DARPA-URI	Growth Studies of CVD-MBE (Maracas,Steimle & Bajaj)
AFOSR-URI	Spatial Light Modulators with Arbitrary Quantum Well Profiles (Bajaj & Maracas)

The following collaborations have been made possible by the establishment of these laboratories.

MOTOROLA Phoenix Corporate research Lab
Prof. D.K. Ferry - Properties of low dimensional structures
Prof. F. Tsen - Picosecond Raman spectroscopy of III-V's
Prof. J. Menendez - Raman spectroscopy of AlGaAs and quantum wells
Dr. S. Myhajlenko - Cathodoluminescence of MBE material
Prof. R.J. Roedel - Anodic oxidation of superlattices
Dr. R. Graham - High resolution TEM of superlattices